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PRELIMINARY EVALUATION OF THE MINI-BALL TARGET SYSTEM

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U S ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

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PRELIMINARY EVALUATION OF THE MINI-BALL TARGET SYSTEM

by

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ABSTRACT

This report covers work that has been done to date on the use of metal spheres as targets for guided missile radar systems. These spheres are fired from a tripod-mounted shotgun. Results are given of the tests made on the properties and use of this device, which has been named the mini-ball target system.

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I. INTRODUCTION

The mini-ball target concept was developed in the hope of obtaining a positive check on guided missile radar systems in a field test that would produce results similar to a tactical situation, yet permit step by step control of variables. The technique was planned and developed by personnel of the Electromagnetic Laboratory, an element of the Army Missile Command's Directorate of Research and Development.

Results of preliminary tests have been encouraging, and all data collected up to this point have tended to confirm the theoretical feasibility of the system. Radar tests using the mini-ball system are not complicated, and cost of the system is negligible when compared with a measurement system using actual guided missiles.

Results of tests made thus far in the program are given in this report. Investigations of mini-ball characteristics and applications are continuing, and future reports will be published as results warrant.

II. DISCUSSION

The development of a guided missile radar system requires methods to measure the system's capability to detect the location and velocity of a target. The worth of any measurement technique depends both on a knowledge of the technique's properties, and the controls that can be maintained on these properties. Usually the characteristics of a transmitted signal are studied to determine the qualities of various sections of the radar system such as transmitter, antennas, or receiver, since a reflected portion of the transmitted signal must carry the target information which is sought.

Laboratories have standard procedures for examining these various sections of a system and determining the effects they have on a transmitted signal, but laboratory tests do not prove the capability of an assembled radar system subjected to actual field use. The system must be tested under conditions where the transmitted signal is received by reflection from a real target. In this situation, the target must serve as a tool or device by which the system's behavior can be examined. Therefore, the properties of the target must be known and controllable.

In order to be useful, a target must reflect either a true sample of the reflected signal, or the reflection characteristics must be predictable. Except for targets of extremely simple geometry, the prediction of reflection properties is usually very difficult. This is especially true where the target's aspect to the signal beam may be changing continuously. If good correlation is expected between characteristics of transmitted and received signals, targets of simple geometries are essential.

The size of the target is also very important in test procedures. The magnitude of the reflected signal intercepted by the receiving antenna must be within dynamic range of the receiver. If the signal is too big, saturation will occur. If the signal is too small, it could be lost in the noise level of the receiver. The strength of the received signal depends on the reflection properties of the target and the range of the target. It is possible for a small target at very close range to saturate a receiver, whereas a large target at a much greater distance might not. The radar cross-section of a target is a relationship which correlates received signal power, transmitted signal power, and the target's range, geometry and substance.

In the development of guided missile radar systems, velocity-of-target measurement capabilities are usually a part of the systems' design. These capabilities must be determined or verified by using the system to measure the velocity of a target which is traveling with a known velocity. Hence, the velocity of a target must be known at each instant during the test period, or the velocity profile must be predictable previous to the test period.

From the foregoing discussion, it is concluded that a target should have at least three fundamental properties to serve as a tool for testing developmental guided missile radar systems. These are:

(1) A shape from which its reflection properties can be predicted.

(2) A size which will produce a predictable radar cross-section that will be compatible with the receiver and range of operation.

(3) A velocity profile that is either known or predictable.

The first of these three properties is obtainable when a spherical object is used. This geometry eliminates any change in signal characteristics because of change in aspect of the target relative to the signal beam. It also gives one of the simpler reflection patterns because the

incidental signal is scattered or defracted in a regular and predictable pattern which depends on the incident wavelength, the target's material substance, and the regularity of its curved surface. Complex interference patterns due to irregular surface shapes are eliminated. The dispersion pattern for spherical bodies may be easily calculated from Maxwell's electromagnetic equations.

The property of the target's cross section can be optimized by examining the solutions to Maxwell's equations for radiation scattered by an object, and by a knowledge of the receiver's dynamic range (including antenna characteristics). A target's radar cross-section is defined as

$$\sigma = 2\pi \left[\frac{S_R}{E_o}\right]^2$$

where σ is the radar cross section, E_o is the amplitude of the incident plane wave, and S_R is the ratio of the scattered wave amplitude to the distance from target to receiver. A solution to Maxwell's equations for scattering from a sphere will give a result as shown in figure 1, where $\sigma/\pi\alpha^2$ is plotted as a function of a/λ, where a is the radius of the sphere, and λ is the incident wavelength. It can be seen that with targets whose radii are approximately the same as the wavelength of the radiation used, there are definite maxima and minima values of the cross section due to resonance effects.

For work at close range, targets normally must be small to prevent saturation. These targets may be of a size where their diameters are approximately the size of the wavelength used. The maxima and minima regions provide areas in which the size of the target can be varied without too much effect on the returned signal strength. In parts of the curve where the a/λ ratio does not fall in or near one of the maxima or minima points, the slope is quite steep. This means that a slight variation in size could cause a large variation in signal strength. Table 1 illustrates this effect for various points on the graph. The first part of the table shows that the diameter can be changed about 0.024 inch without causing more than 1.0 db change in the radar cross section ratio for all maxima and minima points. Part II of Table 1 indicates the change in signal level for fluctuation of the same amount (0.024 inch) for a/λ on the curve which gives a $\sigma/\pi a^2$ value of 1. Since the ratio of target radius to wavelength is critical for small targets, care must be taken in selecting the size of the target as well as the shape.

The property of velocity profile may be predicted by using a properly designed self-propelled target such as an airplane or a long-burning rocket. It may also be predicted by using a ballistic missile whose trajectory can be determined either theoretically or empirically. Theoretical trajectory prediction normally is difficult except for bodies in free space or massive bodies which move rather slowly over short ranges. If small targets of high velocities are used, the equations of motion become rather complex because of the inherent types of drag forces and wind loadings. Empirical trajectory predictions are usually easier to make. However, if bodies of known shape are used, and if these bodies are of rather simple geometry, much information is readily available which can give a velocity profile from a fluid-dynamic theory approach. Even in this case, the answers depend upon certain empirical relationships which at best can only give an approximation. Any theoretical approach must ultimately fit the experimental results, and experimental data are necessary to obtain such correlation.

The method of projecting the missile is immaterial if it causes no deleterious effects on the target, and if the launching velocities are reproducible. Naturally, a system with the least number of variable conditions will be the easiest to reproduce. Expediency, however, also plays a major role. Many functions enter into this term such as mobility, frequency of launch, replacement of targets, and loading of the launcher. Many items must therefore be considered in the selection of a suitable target and method of launching.

III. EXPERIMENTAL

A. Target and Launcher Selection

In view of the foregoing analysis, it was decided to investigate the possibility of using a spherical conductor as a target and launch it as a projectile from a shotgun. Since the bore diameters of most commercial guns would be near the wavelength of microwaves, a gun might be available or one could be readily modified to suit the purposes. Shot-shell loading, although an art, could be controlled within fairly close tolerances. Since no yaw or pitch stability problems are present in a free flight sphere, and since a smooth bore gun would have less chance of marring the surface of the ball than would a rifled gun, a shotgun was considered preferable to a rifle.

Both the size of the ball and the wavelength of the radar signal must be considered in the selection of a target, as the radar cross section is dependent on both factors. The radar system for which the mini-ball target was first used had a carrier frequency of 9.80 KMC. This frequency

gives a free space wavelength of 3.06 cm/sec. Table IV lists the common commercially available shotguns and the radar cross sections that balls which would fit these guns would have at 9.80 KMC.

It is notable from table I that not only does a target whose diameter is proper for a .410 shotgun give a large radar cross section but it is extremely close to a maximum value (See figure 1). This was a very fortunate discovery since it meant that a launching medium was readily available which could not only meet the target requirements with a relatively high radar cross section for a small target, but it could easily meet the expediency requirements. It can also be seen that a 16 gauge or 12 gauge shotgun could have been used almost as effectively, whereas a 20 gauge or 10 gauge gun could not be used.

A .410 shotgun was obtained and its bore was measured and found to be 0.389 inch in diameter at the muzzle. It was decided to use a ball of 0.388 inch in diameter as the target projectile to prevent possible extrusion or jamming at the muzzle. A calculation for a spherical conductor of 0.388-inch diameter gives a radar cross section of -36.5 db/m² at 9.80 KMC.

A supply of balls of the needed size was not readily available, and it was decided to mould the balls from regular gun lead. A completely spherical ball was almost impossible to obtain by the moulding process. Ridges occurred where the mould plates met, air pockets frequently caused dimples in the ball, and flat places were normally present where the sprue was cut. Although most of these surface irregularities were minute, their presence made some reduction in cross-section expected, possibly as much as 3 to 6 db. However, since this method presented a quick and easy solution to the problem of providing good radar targets, moulded balls were used in all tests covered in this report. Equipment used in the moulding and loading process is shown in figure 2. Figure 3 shows a cross sectional view of a loaded shell. Hercules 2400 powder was used as the propellant, with loading pressures kept between 50 and 60 psi.

B. Tests and Results

Due to its spherical shape and negligible angular momentum, a great deal of dispersion was expected using the mini-ball and .410 launcher. Tests were made to obtain a measurement of shot dispersion. An old wooden tripod was modified so that the gun could be mounted in a fixed elevation and azimuth and approximately 35 rounds of ammunition were fired at cardboard targets. At 100 feet, the dispersion pattern was approximately 1 foot in diameter for ten rounds, while at 500 feet, the dispersion pattern was less than 1° of solid angle.

During the dispersion tests, the wooden tripod was found to be unstable, and sighting difficulties occurred because of the type of sights

built into the gun. A telescopic sight was later mounted on the gun to relieve the sighting difficulties, and a new tripod was designed and fabricated. (See figure 4.)

In testing radar systems using the mini-ball targets, very good results have been obtained. In one series of tests made during July 1962, the ball was launched down-range of the radar antenna from positions varying from five feet to over 4,500 feet. The target was picked up by the radar receiver 49 out of 50 times. Results of the tests were such that certain difficulties were found in the radar system design and were able to be corrected. These tests demonstrated the worth of using a tool such as the mini-ball target as a test and evaluation device. During these tests velocities of approximately 1,000 fps were estimated for the mini-ball from pictures of the returned signal projected on an oscilloscope screen. These estimations were rough and only little credit should be placed on this value.

During field tests in October 1962, velocity data for seven launchings were acquired by a special device connected to the radar system. Some of the results of these tests are shown in table III and figure 5. The importance of these results is the consistency of the velocity profile of the rounds as noted by the shape of the curves. It can be seen that the velocity profile falls off by some inverse power function as would be expected from aerodynamic drag considerations. If these data were extrapolated backwards, the initial velocity of the ball would need be much higher than the first point on the graph. The gun was stationed 2,000 feet in front of the radar antenna, and the ball had to be launched into the radar beam. In some instances the ball stayed in the beam for several seconds, while for other shots the ball passed out of the beam after a short interval. A schematic picture of radar beam and ball trajectory is given in figure 6.

Chronograph tests were made to measure velocities of the balls at a range of fifty feet from the gun. Values for these tests are shown in table IV. The mean velocity was about 1,268 fps. Since these values were measured at relatively close range (50 ft.), while the velocities listed in table III were measured at points much further away, considerable difference in the values is understandable. Elevation angles were not available for the shots listed in table III; therefore, extrapolation of the curves back to muzzle velocities was not possible. With the consistency of the curves of figure 5, good correlation of velocity values in tables III and IV would be expected under proper test conditions.

IV. SUMMARY

The mini-ball target has provided an economical and satisfactory device for testing radar systems. It provides a target of large radar cross-section while being small in physical dimensions. Its shape eliminates target aspect problems, and its velocity profile has shown to be reproducible.

The new tripod has been completed and used for radar field testing. The new design has practically eliminated stability problems found in the first tripod. Predictable velocity profiles appear feasible. A measurement of velocity profile should be made by chronographic techniques at various ranges. This would probably give a verification of the velocity data already acquired by radar techniques.

In future tests, steel balls need to be compared with lead balls. If the steel balls prove satisfactory, they should be used in future radar tests. The advantages of steel balls are that they can be made almost perfectly spherical and they will be less subject to damage or distortion due to their hardness. Some reduction in size of the ball would probably be necessary with the present shotgun, or a modification to the bore of the gun might need to be made if steel balls are used in order to safeguard against jamming and destruction of the gun. This reduction in size would not cause any great effect on the radar cross section. At present, steel balls 0.375 inches in diameter are being evaluated. These balls have a α/λ of .16 and a radar cross section of 2.49 cm^2 or -36.0 db/m^2. This compares favorably to the lead mini-balls whose α/λ is .17 and whose cross section is -35.6 db/m^2.

TABLE I

RADAR CROSS-SECTION RELATIONSHIPS FOR METAL SPHERES

Part A

Effect of Varying α / λ in Vicinity of Maxima and Minima Points

α / λ	$\frac{\sigma}{\pi \alpha^2}$	$\left(\frac{\sigma}{\pi \alpha^2}\right)$ 1 db	Range of α / λ at 1 db	Range of α in inches at 9.8 KMC	$\frac{\Delta \alpha}{2}$
0.17	3.7	3.2	0.150 - 0.190	0.181 - 0.229	.024
0.285	0.23	0.27	0.265 - 0.305	0.313 - 0.362	.024
0.365	1.93	1.80	0.345 - 0.385	0.416 - 0.464	.024
0.480	0.50	0.536	0.460 - 0.500	0.554 - 0.603	.024

Part B

Effect of Varying α / λ by ± .024 Inches at Points Where

$$\frac{\sigma}{\pi \alpha^2} = 1$$

$\frac{\sigma}{\pi \alpha^2}$	$\frac{\alpha}{\lambda}$	$\frac{\alpha}{\lambda} - .02$	$\left(\frac{\sigma}{\pi \alpha^2}\right)_-$	$\frac{\alpha}{\lambda} + .02$	$\left(\frac{\sigma}{\pi \alpha^2}\right)_+$	$\left[\frac{\left(\frac{\sigma}{\pi \alpha^2}\right)_+}{\left(\frac{\sigma}{\pi \alpha^2}\right)_-}\right]$ db
1	.235	.215	0.17	.255	.345	20 db
1	.320	.300	1.15	.340	.25	46 db
1	.460	.440	0.76	.480	1.20	16 db

TABLE II

RADAR-CROSS SECTIONS OF SPHERES
THAT FIT COMMERCIAL SHOT-GUNS

Frequency 9.8 KMC

Gun Size	Radius of Bore at Muzzle α in cm	$\frac{\alpha}{\lambda}$	$\frac{\sigma}{\pi \alpha^2}$	σ $M^2 \times 10^{-4}$	σ $\frac{db}{M^2}$
.410 Caliber	.495	.162	3.6	2.75	- 35.6
20 Gauge	.765	.249	0.40	0.730	- 41.4
16 Gauge	.823	.269	0.24	0.510	- 42.0
12 Gauge	.909	.297	0.24	0.623	- 42.1
10 Gauge	.965	.315	0.50	1.463	- 38.4

TABLE III

VELOCITY-TIME DATA FOR "MINI-BALL" TARGETS

USED IN RADAR TESTS, OCTOBER 1962

(See Figure 5)

Test No.	t_1 M-sec	V_1 fps	t_2 M-sec	V_2 fps	t_3 M-sec	V_3 fps	t_4 M-sec	V_4 fps	t_5 M-sec	V_5 fps
1	325	538	830	459						
2	340	563	855	435						
3	400	522	950	410	1700	296				
4	315	589	830	417	1515	320	2480	222		
5	360	610	870	435	1520	334	2440	232	3750	163
6	370	522	870	480	1520	313	2440	236		
7	350	582	830	454	1490	329	2450	220	3750	172

TABLE IV

INITIAL VELOCITIES FOR "MINI-BALL" BY CHRONOGRAPHIC TECHNIQUES

October 1962

Range - Fifty Feet From Muzzle of Launcher

Test No.	Distance between Screens (Feet)	Time Milliseconds	Velocity Feet Sec
1	3.032	2.307	1314
2	3.032	2.335	1299
3	3.032	2.451	1237
4	3.032	2.396	1265
5	3.032	2.474	1225

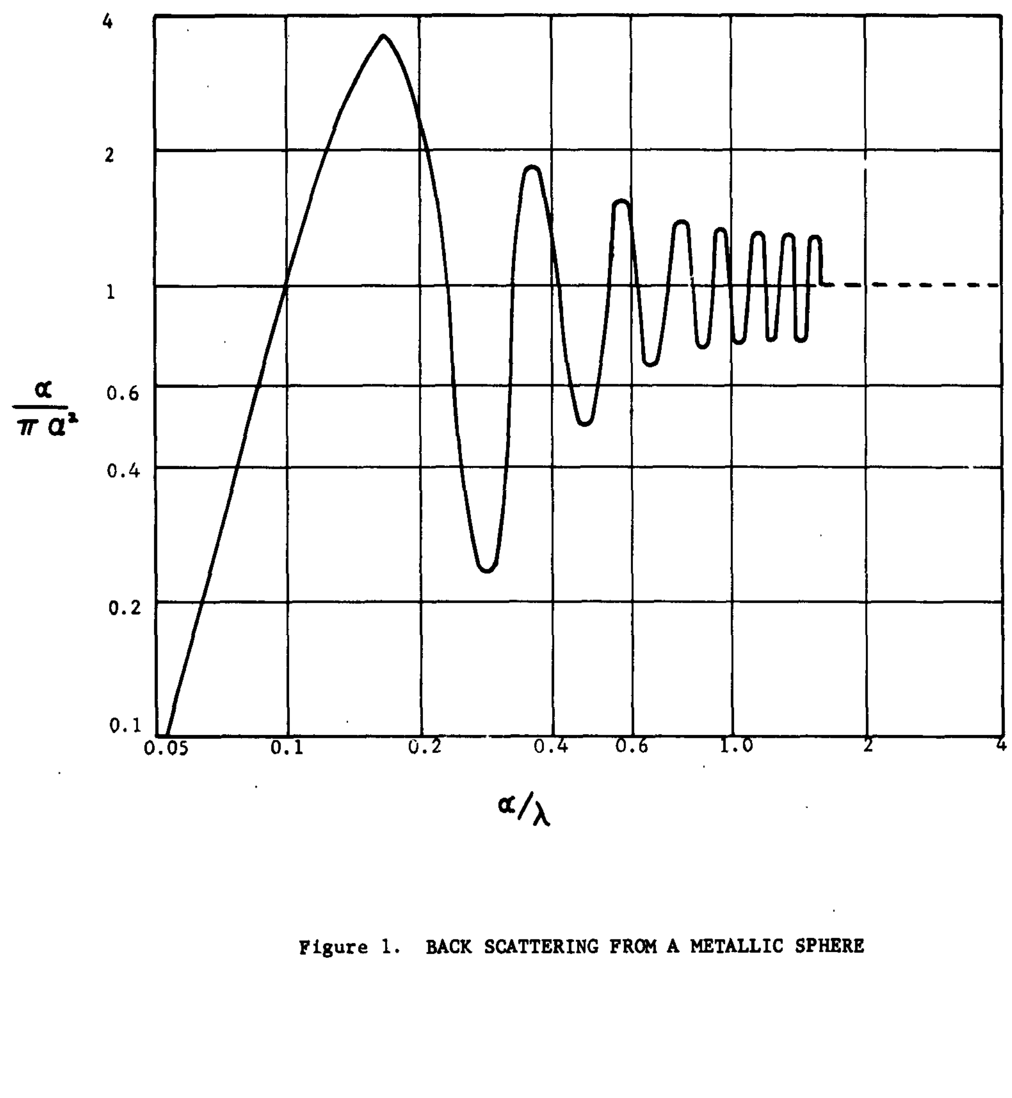

Figure 1. BACK SCATTERING FROM A METALLIC SPHERE

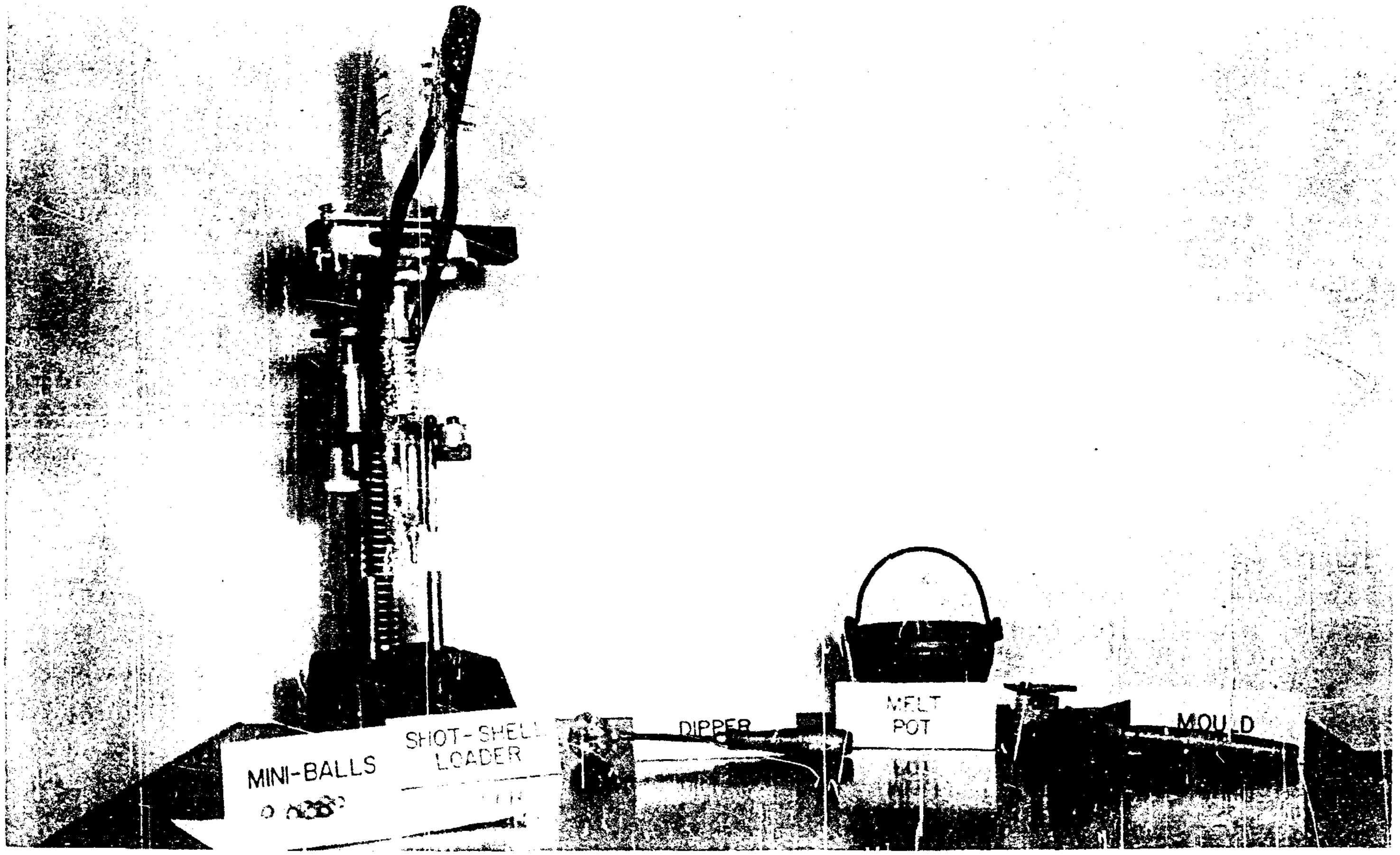

Figure 2. MOULDING AND SHOT SHELL LOADING EQUIPMENT

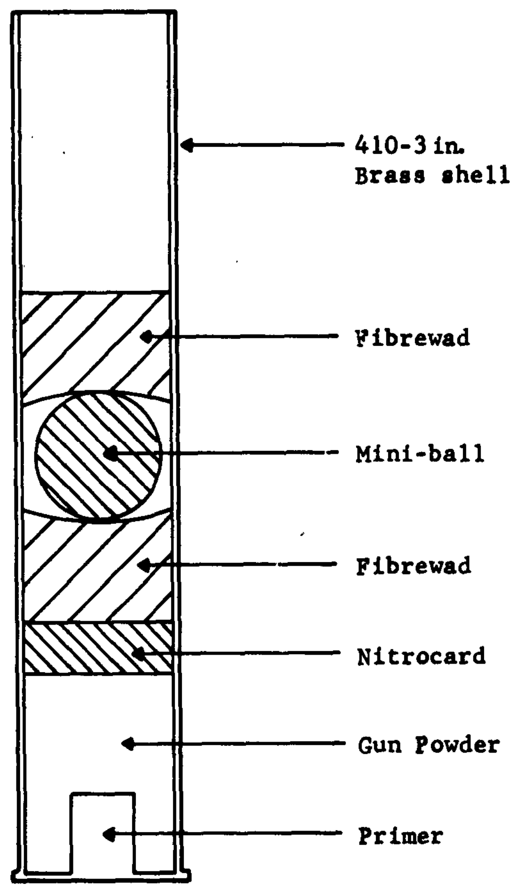

Figure 3. CROSS-SECTION OF LOADED MINI-BALL SHELL

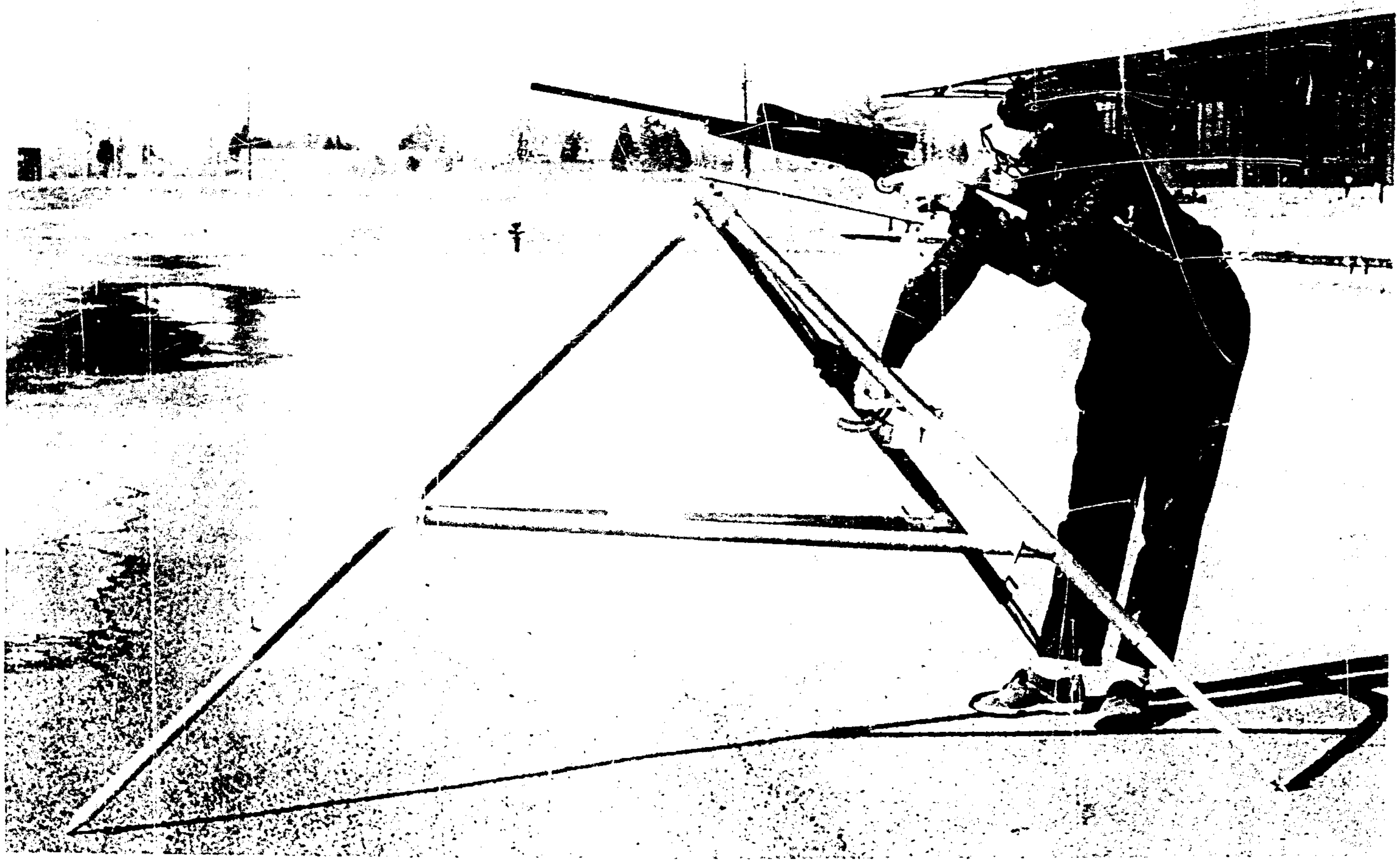

Figure 4. NEW TRIPOD WITH TELESCOPIC SIGHT

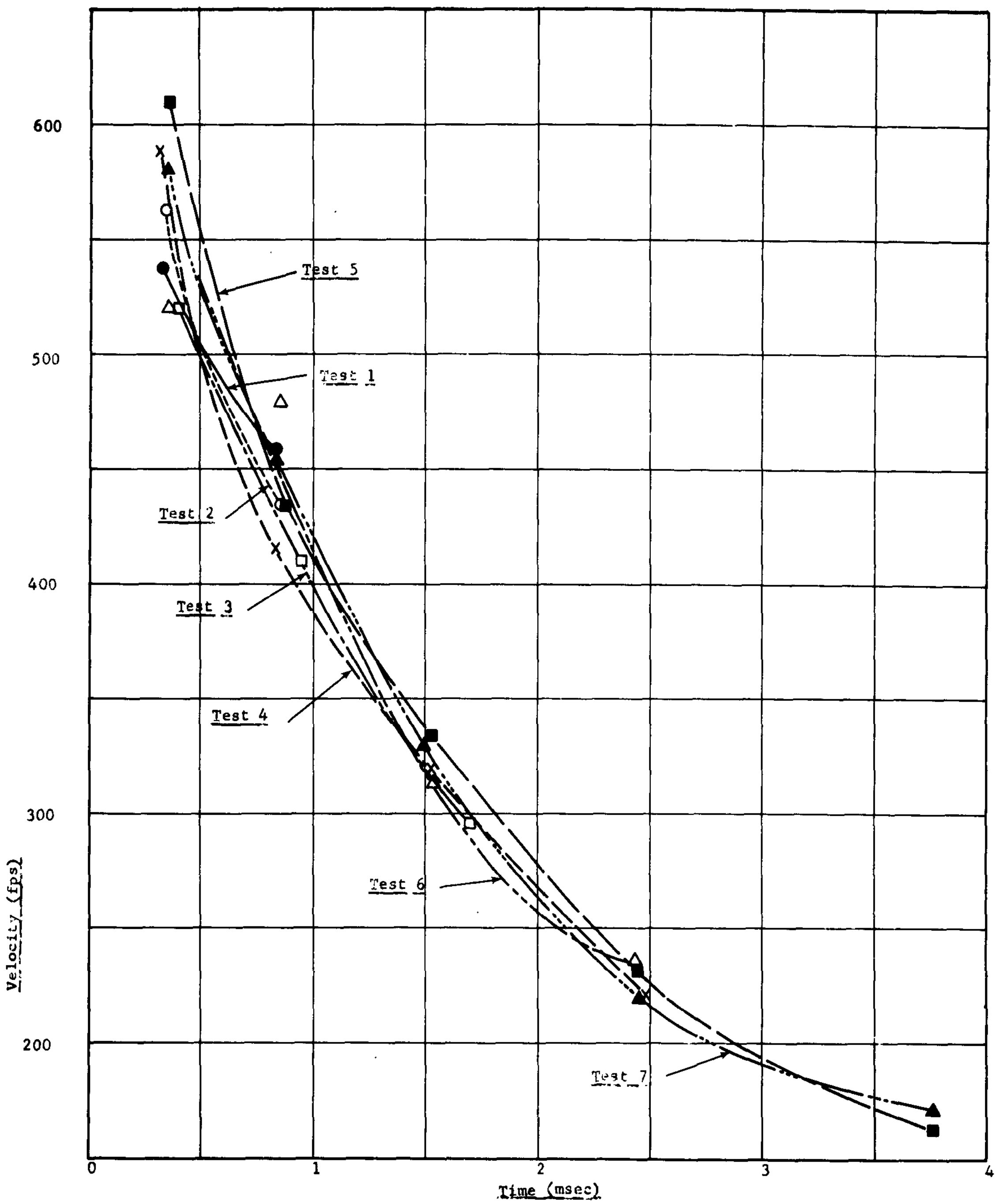

Figure 5. VELOCITY PROFILE CURVES

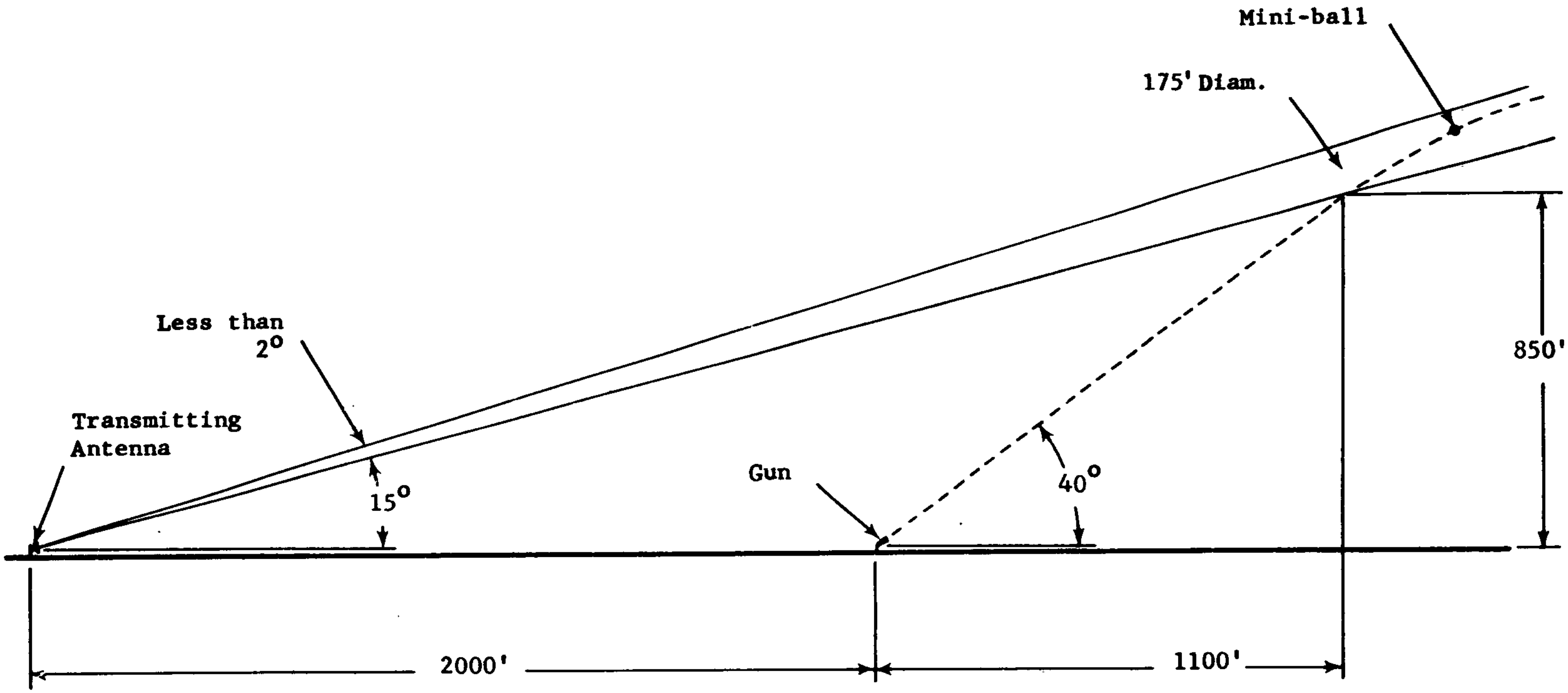

Figure 6. SCHEMATIC DIAGRAM OF RANGE PLOT

APPROVAL:

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PRELIMINARY EVALUATION OF THE MINI-BALL TARGET SYSTEM (U) - Dorwin L. Kilbourn.

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2. Mini-ball targets
3. Radar systems--Performance
4. Radar systems--Test methods
5. Spheres--Radar cross sections
6. Targets--Detection

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